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Naval Aerospace Medical Research Laboratory

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Twelve male subjects participated in two identical experimental series to determine the value of exercising 4 hours daily at one-half Earth gravity (simulated) to prevent loss of exercise capacity and orthostatic tolerance when exposed to 14 days of simulated weightlessness. In one series four subjects exercised at half-gravity (HGE subjects) on treadmills mounted in a human centrifuge and four exercised on treadmills mounted on inclined planes; in the other series the subjects switched exercise devices. Four subjects served as no-exercise controls throughout both series. Orthostatic tolerance was measured in a lower body negative pressure device and exercise capacity was measured with the aid of a treadmill. Additional measurements included: plasma volume and red cell mass, urinary sodium and potassium, and peripheral renin activity. The findings revealed no significant differences between the responses elicited during exercise in the centrifuge or on the inclined plane, hence, use of the latter device will greatly increase cost effectiveness in any future experiments. A difference in LBNP tolerance between the two groups was not demonstrated when measurements were made before and at the end of the deconditioning period and after recovery. There was evidence, however, that the time course of 6:00 A. M. peripheral renin activity differed in the two groups. Exercise capacity diminished in both groups, but there was a twofold greater loss in the control compared with the HGE group. Control subjects manifested greater losses of plasma volume but smaller losses of weight than HGE subjects. No significant differences between the two groups were found in the patterns of urinary electrolytes or the loss of red cell mass. The results are discussed not only in terms of the present experiment but also in terms of their significance for long-range plans involving the use of artificial gravity as a countermeasure on space missions.

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PRA (peripheral renin activity)						
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Red cell mass						
Treadmill						
Exercise capacity						

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SUMMARY PAGE

THE PROBLEM

The primary object of this experiment was to measure the value of exercising four hours daily at one-half Earth gravity (simulated) to prevent loss of exercise capacity and orthostatic tolerance in subjects exposed to 14 days of simulated weightlessness (head-out water immersion and bed rest). A secondary object was to compare the effectiveness of a human centrifuge and an inclined plane in simulating the subgravity level.

FINDINGS

Twelve male subjects participated in two identical experimental series. In one series four subjects exercised at half-gravity (HGE subjects) on treadmills mounted in a human centrifuge and four exercised on treadmills mounted on an inclined plane; in the other series the subjects switched exercise devices. Four subjects served as no-exercise controls throughout both series. Orthostatic tolerance was measured in a lower body negative pressure device, and exercise capacity was measured with the aid of a treadmill. Additional measurements included: plasma volume and red cell mass, urinary sodium and potassium, and peripheral renin activity. The findings revealed no significant differences between the responses elicited during exercise in the centrifuge or on the inclined plane, hence, use of the latter device will greatly increase cost effectiveness in any future experiments. A difference in LBNP tolerance between the two groups was not demonstrated when measurements were made before and at the end of the deconditioning period and after recovery. There was evidence, however, that the time course of 6:00 A. M. peripheral renin activity differed in the two groups. Exercise capacity diminished in both groups, but there was a twofold greater loss in the control compared with the HGE group. Control subjects manifested greater losses of plasma volume but smaller losses of weight than HGE subjects. No significant differences were found in the patterns of urinary electrolytes or the loss in red cell mass. The results are discussed not only in terms of the present experiment but also in terms of their significance for long-range plans involving the use of artificial gravity as a countermeasure on space missions.

INTRODUCTION

Manned space exploration, in centering attention on adjusting to life in a weightless spacecraft, has inevitably called attention to the environment from which man came and must return. Man's adaptation on Earth is not a one-time transaction but a continual interaction with the gravitoinertial force environment. The difference between spacecraft and Earth is not merely 1.0 G but the G loads engendered by the acceleration of gravity and referred to as body weight when man is passive or gravitoinertial force when active. There is general agreement that passive exposure to weightlessness (2, 3, 6, 8, 13) or simulated weightlessness (5, 6, 9, 10, 11) quickly leads to deterioration at organizational levels such as muscle and bone and that eventually the noxious effects will reach cellular and subcellular levels. In order to maintain fitness in a weightless spacecraft, some of the means required to maintain fitness on Earth must be introduced and will be referred to as countermeasures. The real purpose of all countermeasures is not adaptation to weightlessness but its prevention; the object is preservation of adaptation to the Earth's environment.

At this time the only countermeasure ensuring safety in prolonged space missions (and return to Earth) is artificial gravity (9, 12, 14). Two methods have been proposed, namely, exposure to high G loads for short periods in an on-board centrifuge or continual rotation of part of a space station, presumably at fractional G loads (12, 14). However fractional-gravity is generated, its beneficial effects are specific and permanent, i.e., not subject to decay. The goal is to find out how much less than 1.0 G will suffice. The present experiment represented an initial step toward this long-range goal and had two immediate objectives. One was to determine the effectiveness of exercise at one-half Earth gravity in preventing adaptation to simulated weightlessness. The second object was to compare the effectiveness of a human centrifuge and a sloped wall in simulating this G load.

PROCEDURE

SUBJECTS

Twelve male subjects, 20 to 22 years of age, were selected from a group of college students (volunteers) based on the findings revealed in a comprehensive medical and psychological evaluation and personal interview.

METHOD

Exercise at 0.5 G_z was accomplished using specially designed treadmills mounted in a slow rotation room (SRR) or on an inclined plane. The apparatus in the SRR is shown in Figure 1 A and 1 B. Subjects were comfortably supported in the Earth-horizontal plane by a helmet, a 9-inch chest sling, an 11-inch hip sling, and upper and lower leg supports, each on an adjustable vertical cable attached to the 12-foot overhead. They lay on their right side, along a radius, head inward, facing away

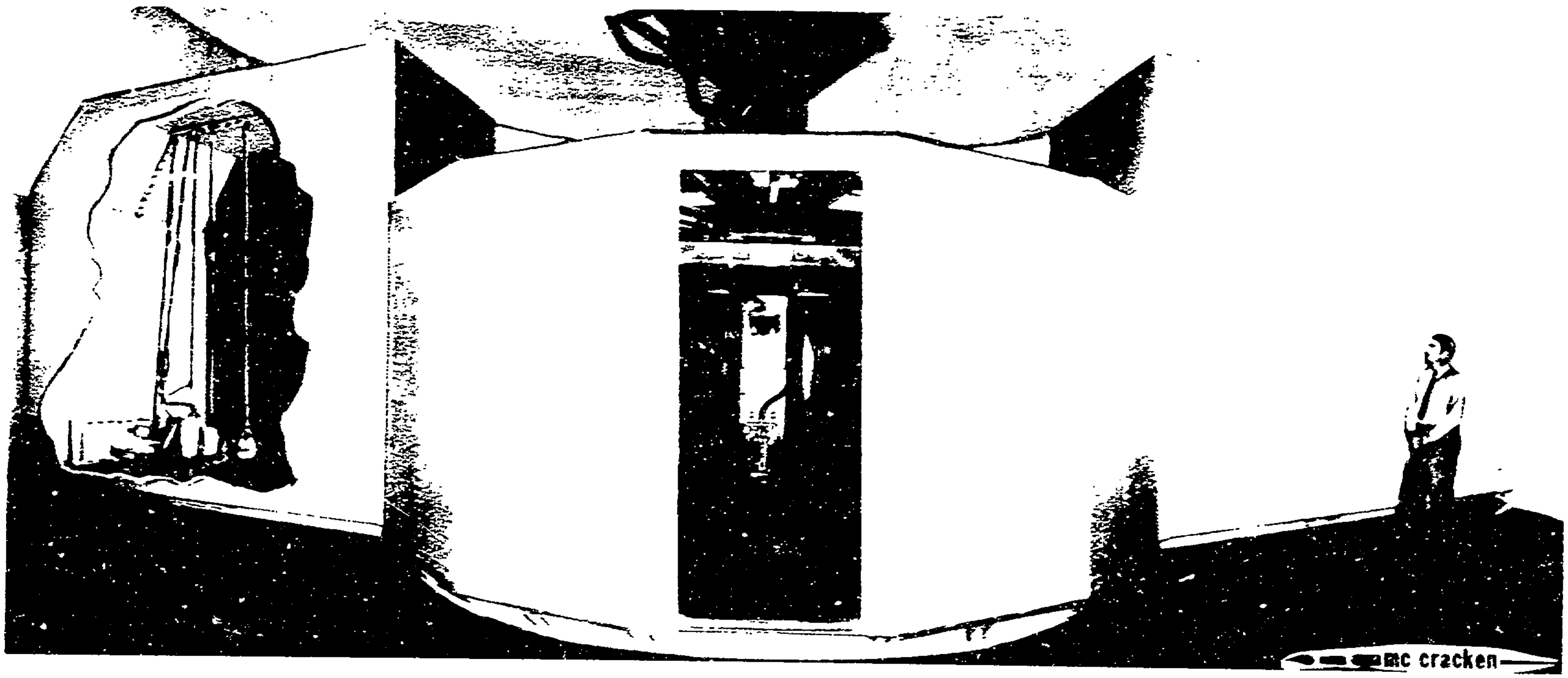

Figure 1 A

Human centrifuge modified at extremities to permit two subjects (one shown) to exercise simultaneously on treadmills when exposed to fractional G levels.

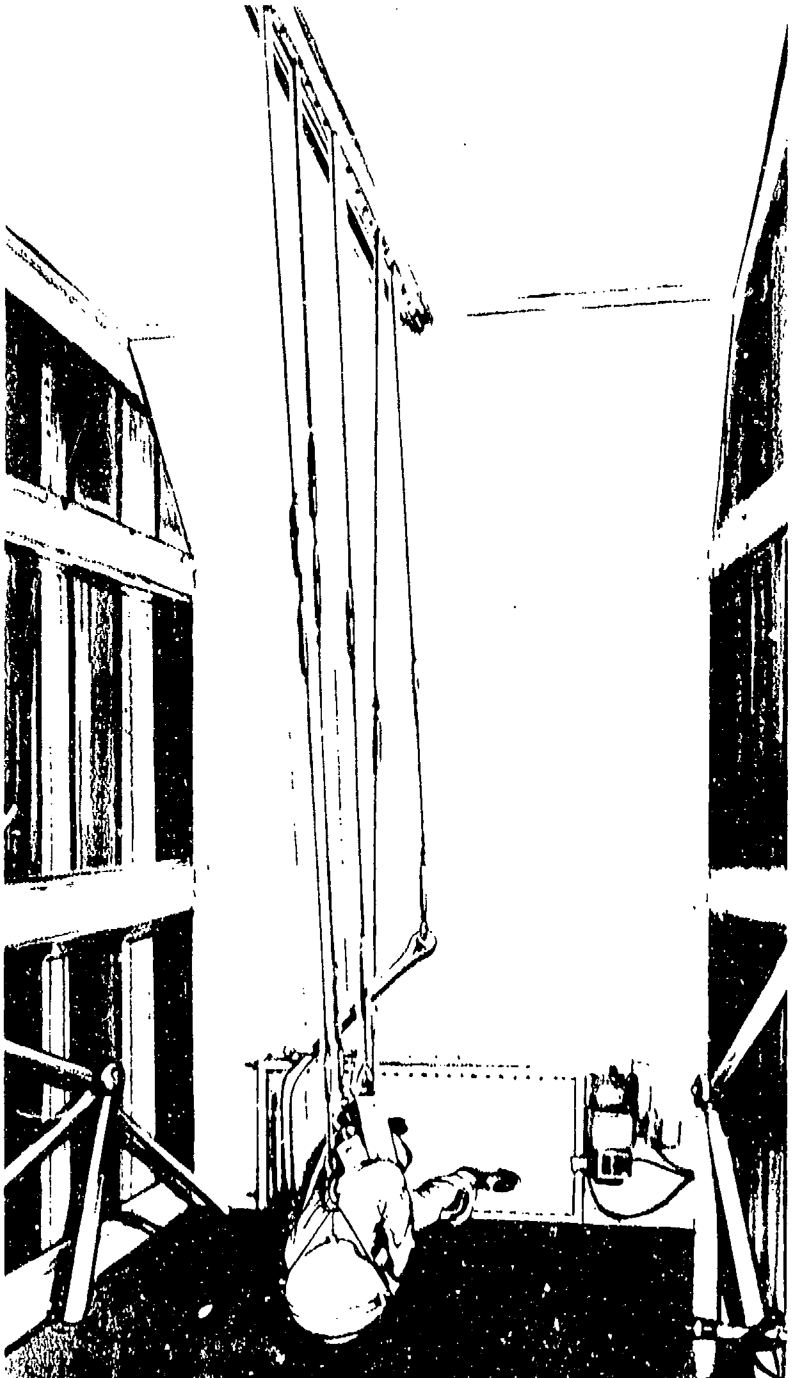

Figure 1B

Detail of suspension harness and specially-designed treadmill in one wing of slow rotation room.

from the direction of rotation. With the man's center of mass at a radius of 19.5 feet, rotation at 3.7 $\pm$ 0.1 RPM generated a force approximately 15% less than 0.5 G_z at head level and 15% more at the feet.

The apparatus using an inclined plane is diagrammed in Figure 2. Subjects were supported by fitted slings on a stationary rack tilted 30° with feet lower than head. The resultant component of the Earth's gravitational vector produced $\pm$ 0.5 G_z force ($\sin 30° = 0.5$) down the long axis of their body (with no head-to-toe gradient) against which they exercised. Each 2 hours of exercise consisted of three 40-minute periods of walking at 2, 3 and 4 mph, respectively, for 20, 10 and 5 minutes with a 5-minute rest between each period. These were intended to be submaximal exercise periods and were performed twice daily. Oxygen consumption ranged from 15-20% of maximum at 2 mph to 25-30% of maximum at 4 mph.

The procedure for measuring orthostatic tolerance using a lower body negative pressure (LBNP) device has been described elsewhere in detail (4). The lower half of the subject's body was placed supine in the LBNP chamber and the airtight seal completed by stretching a latex lower-abdominal-sleeve about the lips of the mold. After baseline data were recorded for 5 minutes, the pressure inside the chamber was lowered 70 mm Hg below atmospheric pressure over a period of 30 seconds. Blood pressure at one-minute intervals, electrocardiogram, and instantaneous heart rate were monitored by a physician at the subject's side and recorded on a UV oscillograph along with respiration and vectorcardiogram. The duration of exposure to the point of "pre-syncopal grayout" was used as the measure of orthostatic tolerance. At endpoint the pressure in the chamber was returned to atmospheric level within 2 seconds and the recording continued for 5 minutes during recovery.

Exercise capacity was measured using a modification of the method of Balke (1), and a precordial electrocardiogram was recorded continuously, beginning 2 minutes before the run while the subject was seated. The subject began running at the constant speed of 500 feet per minute (9.14 km/hr) with the treadmill level, a submaximal warm-up workload. After one minute the slope of the treadmill was increased to 4%, and each minute thereafter the slope was increased another 2% while the speed remained constant. After N minutes of running, a subject had completed a 2 N% grade and in that Nth minute his work expenditure in vertical ascent was 10 NW foot pounds (13.56 NY joules) where W is his weight in pounds. An "exhaustion" endpoint was used with the subject signaling when he felt he could not possibly complete another minute at a 2% higher incline. For 5 minutes during recovery heart rate was measured (half-minute intervals) with the subject sitting. The number of minutes a subject was able to run was used as the measure of his exercise capacity.

Weightlessness was simulated for periods of two weeks using head-out supine water immersion (8 hours) and bed rest for the remainder of the day. Each subject had his own 750-gallon, fiberglas-lined water immersion tank which was filled daily

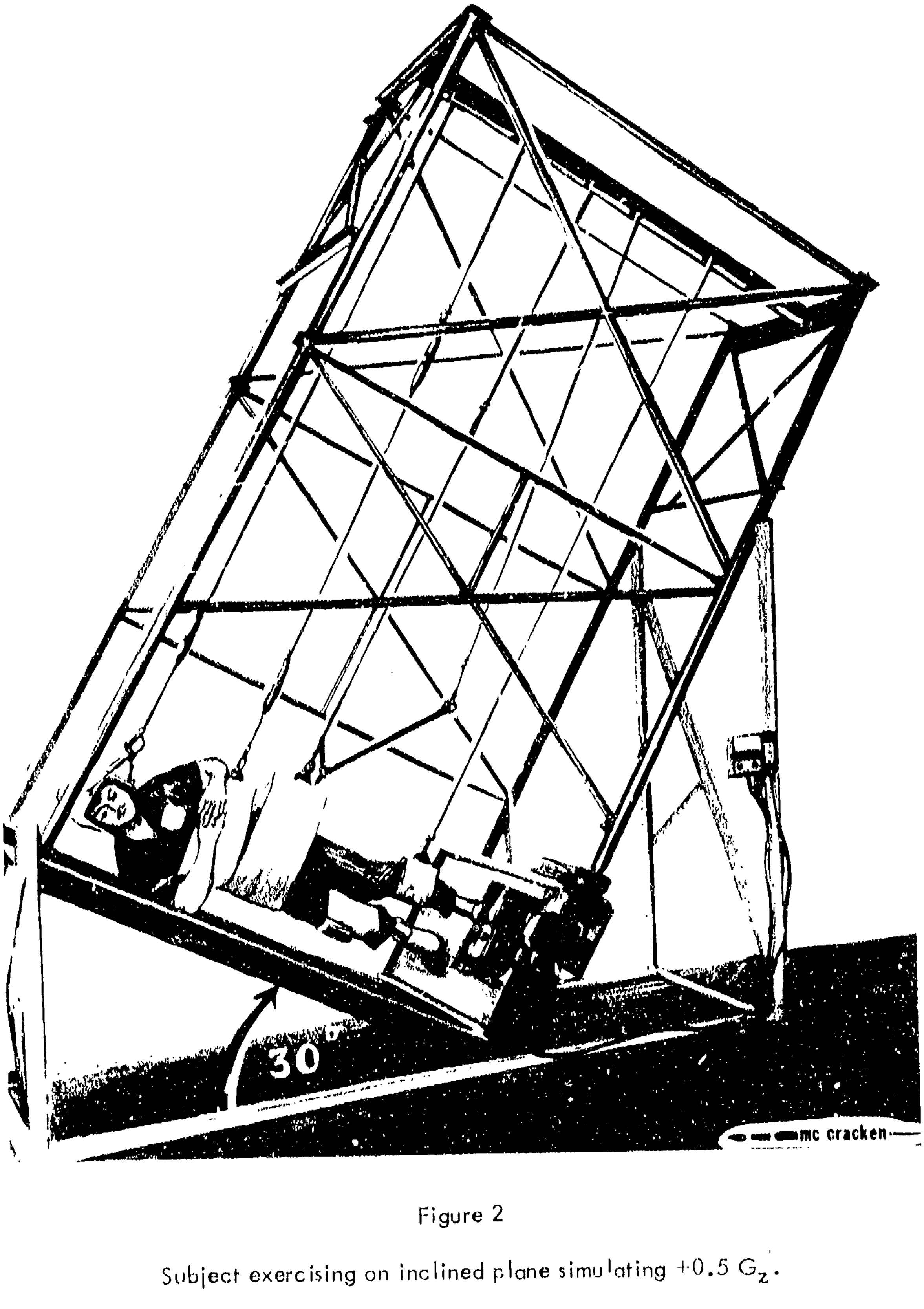

Figure 2

Subject exercising on inclined plane simulating $+0.5\ G_z$.

with isotonic saline and maintained at 95 ±0.5° F by thermoregulator. During the 14-day periods, all subjects were continually supine; they were transferred on stretchers and were required to use bedpans. Though allowed up on one elbow to eat, they were never allowed to sit up or experience full Earth-gravity along their longitudinal axis. The subjects were provided a regular hospital-selection diet containing at least 5 grams of NaCl with no caloric restriction. Canned juices, water, and milk were offered frequently throughout the day. Although tobacco and alcohol were prohibited, snacks brought during visiting hours were not restricted. This was intended to benefit morale as well as to satisfy any craving for salt, water or food. Daily body weight (A. M.), intake and output, vital signs and nursing notes were recorded by hospital corpsmen.

Daily 24-hour urine collections extended through the first 48 hours of recovery. In addition to routine urinalysis, the urine was examined for total volume, osmolality, sodium, potassium and creatinine. In addition to routine CBC with differential count and sedimentation rate, serum sodium, potassium, chloride, creatinine, urea, total protein, albumin and osmolality were measured before, bi-weekly during deconditioning, and on the third day of recovery. At 6:00 A. M. on the first day of immersion and on the first day of recovery, plasma volume and red cell mass were determined from blood drawn before and 15 minutes after intravenous RISA injection.

Peripheral renin activity (PRA) response to orthostatic challenge was determined by radioimmunoassay of 3-hour angiotensin 1 activity by the method of Haber (7) before and within one minute of LBNP during baseline testing and on Days +1 and +3 after deconditioning. PRA was also determined before and immediately after the morning 2 hours of half-gravity exercise on the eighth and fourteenth day of the two-week immersion periods. PRA was also measured at the same time in controls undergoing immersion for comparison.

General Plan

The subjects were arbitrarily divided into two sets, and tests were conducted on each set during alternate months of a four-month period. Each set comprised two subjects who served as controls, two who exercised on the inclined plane and two who exercised in the SRR. During the two-week deconditioning period all subjects spent four hours twice a day in the water. The control subjects spent the remainder of the day at strict bed rest. The other four subjects exercised for two hours twice daily (against $+0.5\ G_Z$) for a total of $2\ G_Z$ hours/day and spent the remainder of the time at bed rest. In the week before each deconditioning period, the subjects (who had become familiar with all procedures and devices) were tested on three separate days to determine their baseline orthostatic tolerance and exercise capacity. At least 4 hours intervened between LBNP and exercise tests.

After each of the two-week deconditioning periods, the subjects were retested for orthostatic tolerance and exercise capacity on days 1, 3, 7 and 10. On the first

day after deconditioning, each subject was returned to bed rest immediately following his LBNP testing and ate lunch at least two hours before his treadmill run in the afternoon. In an attempt to prevent acute orthostatic hypotension from interfering with treadmill performance, each subject arose from bed one hour before his exercise test and was allowed to walk (escorted) about the building and outside. For baseline tests and tests on all other recovery days, the subjects were not required to return to bed after the morning LBNP runs.

In order to compare the fractional gravity simulational capability of these two methods, the rotating room and inclined plane, each group of six subjects returned to repeat the entire sequence five weeks after the end of their first deconditioning period. During this second exposure the HGE pairs switched fractional gravity devices while the controls remained the same. This yielded data for eight controls and sixteen HGE subjects.

RESULTS

Findings were analyzed by a split-plot factorial analysis of variance having one between-subjects' measure (control, centrifuge, inclined plane) and one within-subjects' measure (time). One HGE subject, during his second two-week deconditioning period, withdrew from the program after ten days and, therefore, a least-squares solution was computed. The subjects' second deconditioning period did not produce any results significantly different from the first, therefore, the data presented here combine both exposures. No significant differences were found between the effects of exercise in the centrifuge and on the inclined plane so these findings are combined into one exercise group ($n = 16$) for comparison with the control group ($n = 8$). When differences across time were found, a Tukey's HSD test for pairwise comparisons was used to identify which days varied significantly. The key parameters which showed significant changes across time are presented in Figure 3 for comparison.

Orthostatic tolerance was markedly reduced in all subjects after two weeks of simulated weightlessness $F(4, 84) = 27.2761$ ($p < .01$) (Figure 3). When measured on abandoning bed rest the morning of Day +1, LBNP tolerance had fallen in control and HGE groups, respectively, to 40 and 46% of baseline values. By Day +3, however, within 48 hours of returning to normal ambulatory activity, LBNP tolerance had returned to control values. HGE subjects were indistinguishable from controls in the loss and recovery of LBNP tolerance throughout the entire experiment.

Exercise capacity, on the other hand, remained higher in HGE than in control subjects (Figure 3), but all subjects showed a statistically significant loss, $F(4, 80) = 12.730$ ($p < 0.01$). The reduction was, on Day +1, 1.3 minutes in control subjects (baseline 7.4 minutes) and 0.6 minutes in HGE subjects (baseline 7.2 minutes). On Day +3, the loss of exercise capacity still persisted in the controls who remained 0.9 minutes below baseline value ($p < 0.01$). HGE subjects, on the other hand, were back to within 0.3 minutes of their baseline performance by Day +3, which is not a

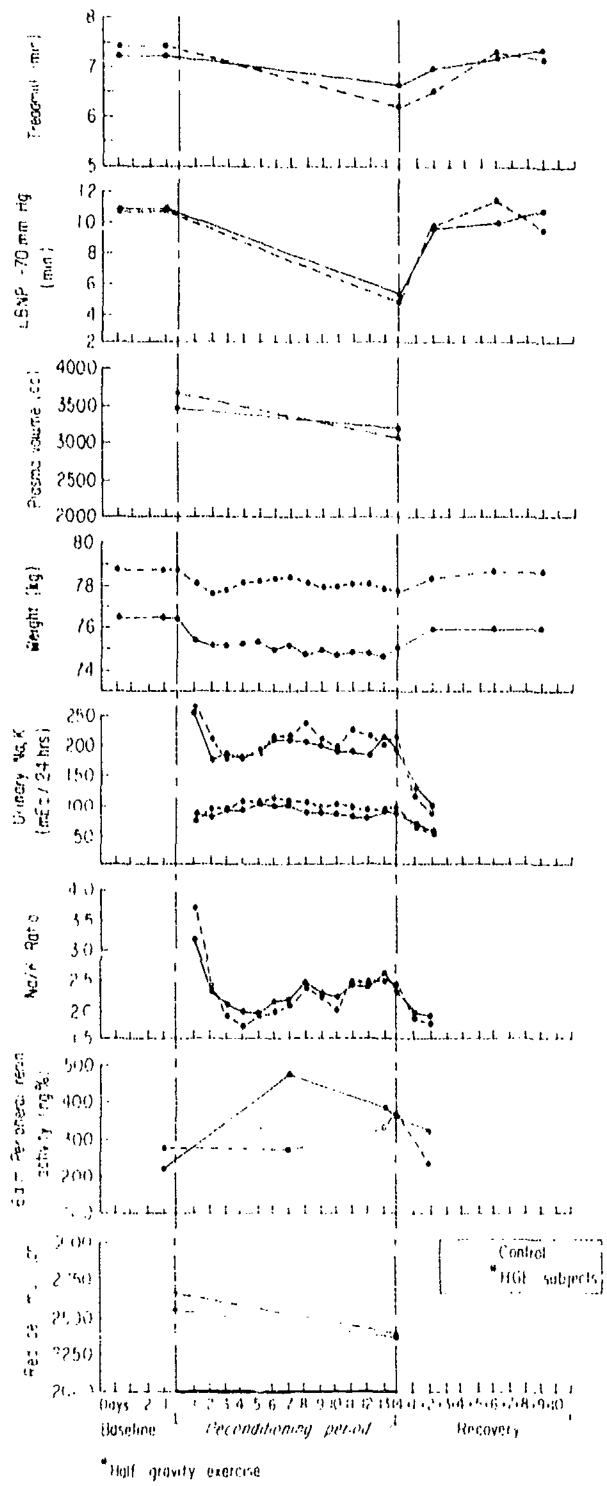

Figure 3

A comparison of findings obtained in half-gravity exercise group (n = 15) and control group (n = 8). Measurements of key parameters are shown for periods before, during and after deconditioning (head-out water immersion and bed rest).

statistically significant difference. On Days +7 and +10, exercise capacity had returned to baseline levels in control subjects and did not differ significantly from values in the HGE group.

Both HGE and control subjects manifested a significant loss of plasma volume over the two-week deconditioning period, $F(1, 21) = 45.235$ ($p < 0.01$) (Figure 3). This loss was significantly greater ($p < 0.01$) in control subjects, 710 cc of 17.0% of their plasma volume, as compared with 287 cc or 8.4% in HGE subjects.

Both groups showed a significant, though smaller loss of red cell mass than plasma volume, $F(1, 21) = 49.9676$ ($p < 0.01$) (Figure 3). Control subjects lost an average of 275 cc (10.4%) while HGE subjects lost 190 cc (7.4%).

Both groups lost a significant amount of body weight during the two-weeks deconditioning, $F(4, 84) = 13.5163$ ($p < 0.01$) (Figure 3). The average weight loss was 2.3 pounds for control subjects and 3.1 pounds for HGE subjects. After returning to normal activity for 48 hours, the control subjects were 1.0 pounds below baseline weight, and HGE subjects were 1.2 pounds below baseline ($p < 0.05$). Both groups remained 1.0 pounds below baseline weights on Days 7 and 10 of recovery.

The pattern of daily weight change during the fourteen days of deconditioning differed between control and HGE subjects, $F(13,273) = 1.9818$ ($p < 0.05$). Control subjects lost 2.4 pounds in the first two days of deconditioning after which they stabilized at approximately two pounds below baseline. HGE subjects lost 2.6 pounds in the first two days but continued to show a weight decrease throughout deconditioning. From the sixth to the fourteenth day an additional 1.6 pounds were lost ($p < 0.05$).

There were no significant differences in urinary sodium and potassium between control and HGE subjects (Figure 3). During the fourteen days of bed rest and water immersion, urinary sodium output was the greatest in the first 24 hours, averaging 256 mEq/24 hrs; during the next four days, the urinary sodium output was significantly lower ($p < 0.01$), totaling, respectively, 188, 182, 177 and 190 mEq/24 hrs. Then, during the sixth, seventh and eighth day, the urinary sodium rose, respectively, to 211, 210 and 216 mEq/24 hrs. Urinary sodium values then settled to the lower levels of 204, 191, 202, 195, 210 and 195 mEq/24 hrs during the last six days of deconditioning. When the subjects resumed activity, urinary sodium fell to the lowest levels of all ($p < 0.01$), namely, 122 and 94 mEq/24 hrs, respectively, in the first two days.

During the first two days of deconditioning, urinary potassium was, respectively, 81.8 and 85.2 mEq/24 hrs. It rose the next five days, respectively, to 92.2, 96.7, 100.9, 101.9 and 101.4 mEq/24 hrs and then settled back towards the initial levels at 92.1, 91.3, 91.4, 85.2, 83.2, 88.8 and 87.4 mEq/24 hrs, respectively, for the last seven days of deconditioning. On return to normal activity, urinary potassium fell ($p < 0.01$) to 65.5 and 51.9 mEq/24 hrs, respectively, for the first two days.

The ratio of urinary sodium to potassium was highest during the first 24 hours of bed rest and water immersion for both groups, $F(15, 315) = 10.031$ ($p < 0.01$) (Figure 3). This ratio of 3.33 contrasts with the two periods when the ratios were lowest, namely, Days 4 and 5 of deconditioning (1.85 and 1.90) and the first two days of recovery (1.88 and 1.82). The urinary sodium to potassium ratio was lower on these four days than on Day 13 of deconditioning when this ratio reached 2.54 ($p < 0.05$).

Peripheral renin activity (6:00 A. M.) increased from a baseline of 237 ng% to 366 ng% by the fourteenth day of deconditioning, and the next morning, before other testing, PRA was 361 ng%. After two days of normal activities, the 6:00 A. M. PRA had fallen back, respectively, to 287 ng%, $F(4, 84) = 6.035$, ($p < 0.01$) (Figure 3). Control and HGE subjects showed a significant difference in their 6:00 A. M. PRA only once, namely, at the beginning of the second week of deconditioning with values of 269 ng% (control subjects) and 473 ng% (HGE subjects), $F(4, 84) = 3.053$ ($p < 0.05$).

PRA measured immediately after HGE subjects exercised 2 hours in the morning showed no statistically significant change from 6:00 A. M. values measuring 410 ng% and 458 ng%, respectively, after deconditioning periods of one and two weeks (Figure 4). On the same occasion PRA measured in control subjects (after 2 hours supine water immersion) were 224 ng% and 290 ng%; these values were not significantly different from 6:00 A. M. levels. PRA increased after exposure to LBNP, averaging 295 ng% before and 541 ng% after, $F(1, 20) = 55.80$, ($p < 0.01$. In contrast, there was no significant difference in the magnitude of the renin response to LBNP either between groups of subjects or between the conditioned and deconditioned state $F(2, 40) = 2.7639$ (n. s.) (Figure 5).

DISCUSSION

All of the relevant experimental data support the conclusion that the effects of exercising at 0.5 G_z in a rotating room and on an inclined plane are indistinguishable. The greater cost-effectiveness of the inclined plane device compared with a rotating room is an important consideration in planning a program dealing with the effects of exposure to fractional gravity for whatever purpose.

At the end of the deconditioning period the decline in exercise capacity was greater in the control than in the HGE group, which was expected; what was not expected, however, were the identical declines in LBNP tolerance in the two groups. If LBNP tolerance had been measured at frequent intervals throughout the deconditioning period, curves depicting the time course of changes in LBNP tolerance in the two groups might have revealed differences.

At the beginning of the second week of deconditioning, 6:00 A. M. PRA was elevated only in the HGE group. Although two hours of half-gravity exercise were not immediately associated with a rise in PRA (an unexpected finding), the cumulative effect of such exercise twice daily, along with diuresis, fluid shifts and blood pressure changes

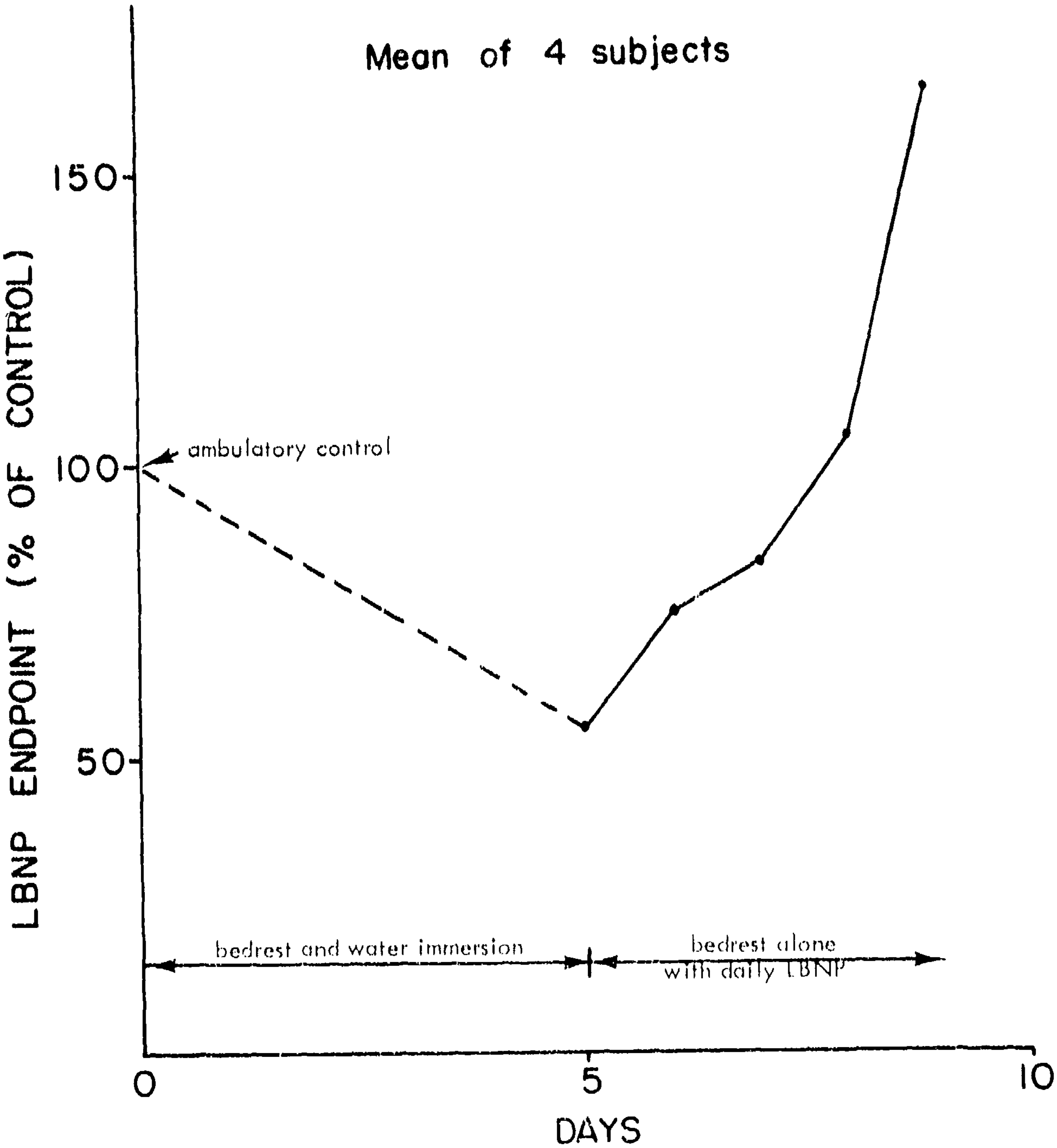

Figure 4

Restoration of orthostatic tolerance with daily LBNP.

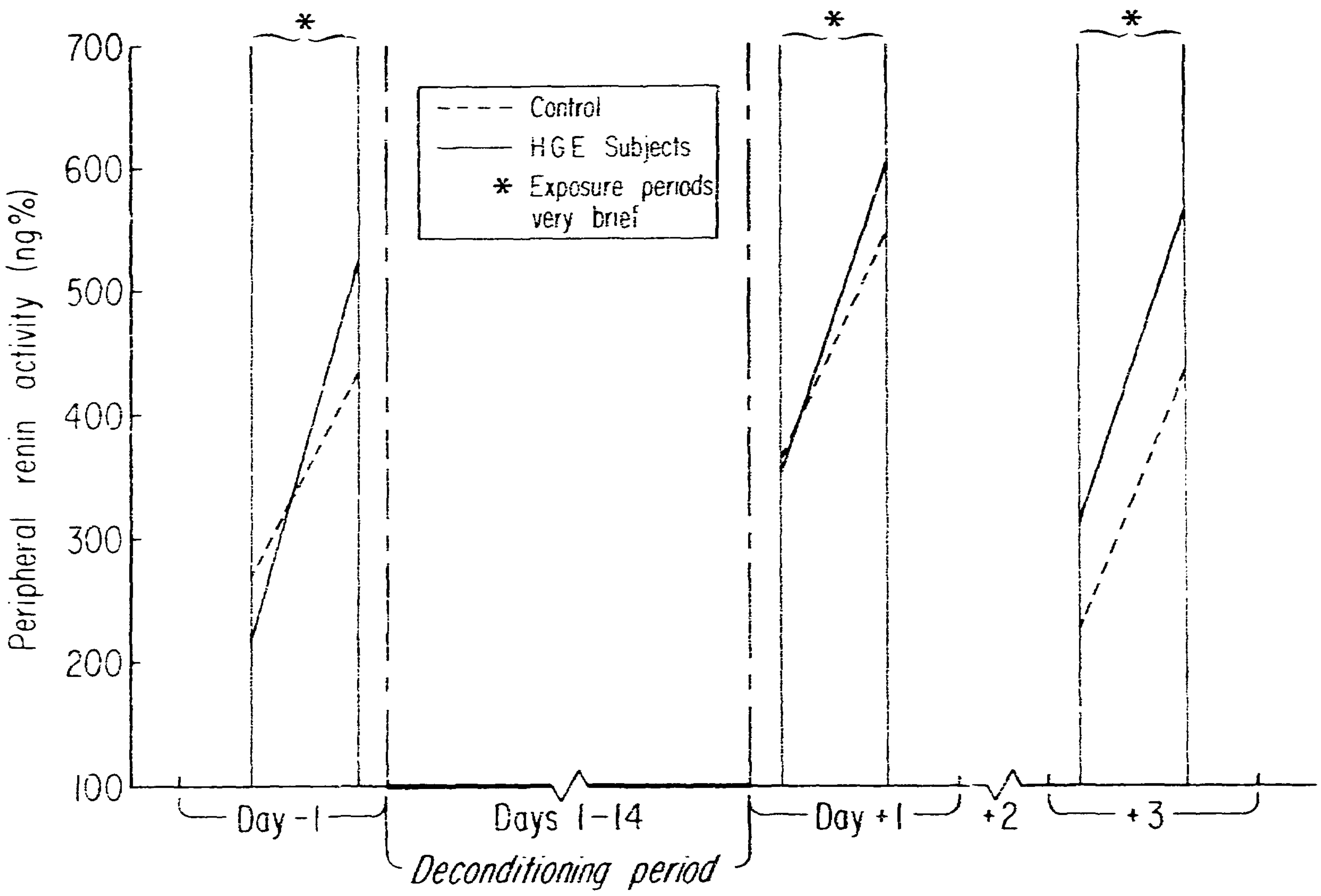

Figure 5

PRA levels before and after exposure to -70 mm Hg LBNP prior to deconditioning and during recovery.

was, apparently, sufficient to elevate PRA, which was still at baseline levels in the control group. This elevation may have accounted for HGE subjects having a smaller loss of plasma volume than control subjects. Whereas diurnal variation would be expected to cause a decrease in PRA during the morning half-gravity exercise, a small increase in PRA (n. s.) was seen at this time after two weeks of deconditioning in the HGE subjects. One may speculate that this small increase in PRA signifies a lowered threshold sensitivity to orthostatic stress, perhaps as a result of diminished vascular tone.

It is worth noting that, although control subjects lacked the postural stimulus to increase PRA, perfusion at the juxtaglomerular level was ultimately affected by adaptation to simulated weightlessness. This is contrary to the notion that bed-rest diuresis is no more than compensation for the increased circulating blood volume caused by the supine position. Although no significant differences were found in the percent increase in PRA response to LBNP among baseline, deconditioned, and recovery states, the subjects tolerated this orthostatic stress for less than 5 minutes when deconditioned and 10 to 11 minutes during baseline conditions and after recovery. Peripheral renin activity stands out as the key measurement indicating early adaptation to weightlessness and, at least at the renal level, a sign of circulatory deconditioning. The elevation of 6:00 A. M. PRA after two weeks of deconditioning was consistent with decreased plasma volume and accords with experience in Apollo spaceflights (3).

The loss of exercise capacity, which was still substantial on the third day of recovery in control subjects, emphasizes the deconditioning effect of simulated weightlessness. The small, though significant, 8.3% loss in treadmill endurance found in HGE subjects on Day +1 is probably due to the relatively low level of exercise demanded of them. All subjects felt their previous normal daily activities were far more vigorous than these periods of walking at only 2, 3 and 4 mph. Further experience with these treadmills indicates that most subjects are more comfortable jogging at 5 and 6 mph than walking fast at 4 mph. It would be simple to increase the work of the exercise task to maintain better the baseline exercise tolerance of active male subjects. Fractional-gravity exercise apparently did reduce the plasma volume loss of HGE subjects (8.5%) in comparison to control subjects (17.0%). Other investigators (6, 11) have shown that supine isometric and isotonic exercise retards the loss of plasma volume during fourteen-day bed-rest studies but does not help preserve G_z tolerance.

The significant weight loss in both groups is greater than what may be accounted for by plasma volume loss alone. Other extracellular fluid loss is most likely contributory; however, HGE subjects lost an average of 0.8 pounds more than controls. This additional loss may be caloric in origin. During the four hours of daily exercise, HGE subjects not only expended significant amounts of energy but also were unable to have snacks or take fluids which were available to controls resting under nearly basal conditions. Over-all weight on Day +3 of recovery remained 1.1 pounds below baseline ($p < 0.05$), suggesting that a portion of the weight loss came from elsewhere than a fluid compartment where restoration is rapid. A 1.0 pound deficit, though not

statistically significant, persisted in all groups through Days +7 and +10, and complaints of loose-fitting clothing were common among participants in the project.

The fact that the urinary sodium and potassium values did not differ between groups indicates that the half-gravity exposure was not sufficient to influence the electrolyte balance of the subjects or to prevent adaptation to the simulated weightlessness. Urinary sodium loss, which was greatest the first day of deconditioning, decreased and stabilized during the remaining thirteen days with a transient rise on Days 6, 7 and 8 in both groups. The urinary potassium which was lowest on the first day of diuresis, rose gradually, peaked during Days 5, 6 and 7, and returned to intermediate levels for the remainder of the deconditioning. The fall in urinary sodium/potassium ratio from 3.3 on the first day of immersion to less than 1.9 on Days 4 and 5 was highly significant. This may reflect the fluid shift from the intracellular to the extracellular space to replace that lost during the initial diuresis with consequently more potassium available for urinary excretion. Though the major weight loss and diuresis was during the first forty-eight hours of deconditioning, additional changes in electrolyte excretion patterns occurred during the first eight days and were even found as late as Day 13. This makes it very difficult to predict that further changes would not occur were the deconditioning period extended. On the other hand, a new steady state of adaptation in weightlessness might ultimately be reached with reduced total body water and respiratory and renal compensation for the relative intracellular acidosis and extracellular alkalosis produced by the shift of potassium and hydrogen ions. The fall in urinary sodium and potassium during the first 48 hours of recovery demonstrates how quickly the kidneys can recoup these losses and re-adapt to Earth gravity.

Lastly, it is necessary to comment briefly on the significance of our findings in terms of the generation of artificial gravity in space flight. In a space base, part of which rotates continually, the astronaut might spend four hours of the day in the weightless (nonrotating) part and the remaining 20 hours lying, sitting, standing, or walking, say, at 0.5 G. The beneficial effects of artificial gravity on the musculoskeletal system would be least during sleep, when the antigravity muscles would be relaxed and the direction of force at right angles to the long axis of the body. It is difficult to equate the musculoskeletal effects when seated, standing or walking (for the remaining 12 hours) with 4 hours' exercise (simulated in our experiment) but similarities outweigh differences.

Our data raise the important question whether loss of orthostatic tolerance is a handicap at one-half Earth gravity. In any event, orthostatic tolerance is readily preserved using LBNP devices (4), hence provides little justification for generating artificial gravity. Our findings clearly indicate beneficial musculoskeletal effects at 0.5 G, but the period of exposure was too short to establish the point when exercise capacity remains constant. Our findings suggest it would be worthwhile to repeat the experiment at the same G load but make provisions not only for much longer exposure but also better simulation of the astronauts space base activities while seated, standing or exercising. These "activities" should be designed to reflect actual living and

working conditions aloft and avoid exercises falling in the category of directed countermeasures. In other words, it is highly desirable to determine separately the beneficial effects of ordinary living and working aloft and attempts to use increased amounts of exercise as a specific countermeasure.

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